**Before the**
***Federal Communications Commission***
**Washington, D.C. 20554**

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Facilitating Opportunities for Flexible, Efficient, | ) | |
| and Reliable Spectrum Use Employing | ) | ET Docket No. 03-108 |
| Cognitive Radio Technologies | ) | |
| | ) | |
| Authorization and Use of Software Defined | ) | |
| Radios | ) | |
| | ) | |

# COMMENTS OF SHARED SPECTRUM COMPANY


William J. Byrnes

7921 Old Falls Road
McLean, VA 22102-2414
703-821-3242

Mark A. McHenry

Alexe E. Leu

8133 Leesburg Pike, Suite 220
Vienna, VA 22182
703-761-2818 x 103


April 5, 2004

## TABLE OF CONTENTS

**SUMMARY**

The Commission should adopt a policy in favor of authorizing frequency-agile cognitive radio systems using spatial and temporal holes, initially on a licensed basis, to operate in substantial portions of the VHF and UHF bands.

Dynamic sharing of spectrum by cognitive radios is best achieved by hole filling rather than by underlay. Dynamic sharing can provide a system that will evolve over time to take into account changing regulatory requirements, experience in operation, and shifts in the degree of usage among primary users in each band. This will obviate the need in the future simply to kick out older less efficient users of spectrum to make room for newer more attractive and efficient users. Initially, cognitive radios should be operated on a centrally controlled system basis.

The full benefit of cognitive radio will only be realized when a sufficient number of bands is authorized to permit the inherently flexible technology to adapt to a variety of spectral environments while achieving both a very high degree of interference avoidance and a high quality of service.

Primary licensees should be permitted entry into secondary markets on terms that assure no unfair or competitive advantage over independent users of cognitive radio.

**Before the**
***Federal Communications Commission***
**Washington, D.C. 20554**

| | | |
|---|---|---|
| In the Matter of | ) | |
| | ) | |
| Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies | ) ) ) | ET Docket No. 03-108 |
| | ) | |
| Authorization and Use of Software Defined Radios | ) ) | |
| | ) | |

# COMMENTS OF SHARED SPECTRUM COMPANY

**Introduction**

Shared Spectrum is a newly formed company developing broadband wireless equipment optimized for secondary spectrum markets applications. Shared Spectrum's goal is to offer technology and equipment to fully realize the potential of the dynamically shared spectrum market as rapidly as possible. The technology to accomplish this could be fielded in a few years, but regulatory issues (technical and spectrum availability) now limit its development. Shared Spectrum has conducted extensive spectrum occupancy surveys that indicate that spectrum utilization is low in most bands, even in urban areas.

The problem is access to spectrum, and not of spectrum shortage. Advances in broadband wireless network technology being developed by the Department of Defense along with the Commission's Spectrum Policy Task Force's (SPTF) recommendations will provide a profound improvement to wireless communications over the next few years. The Task Force's concept of Interference Temperature enables dynamic, adaptive spectrum use that would solve the spectrum access problem. These new developments will lead to a very large increase in the widespread availability of high capacity wireless communications in both urban and rural regions and provide a significant cost reduction due to reduced spectrum acquisition costs.

Shared Spectrum believes that the most effective technology and future paradigm for dynamic sharing will consist of systems that find and use "holes," both spatial and temporal, for their transmissions. Shared Spectrum is developing such a system. The Shared Spectrum system identifies fallow spectrum on a dynamic basis and uses it if it meets an appropriate selection algorithm.

**Initial Operation of Smart Radios Should Take Place on a Centrally Controlled System Basis**

Holes that are large and durable obviously preferred to holes that are small and evanescent. That proposition can be reflected in a well designed algorithm, and the algorithm can be adjusted over time to reflect increasing degrees of confidence in operational experience and increasing congestion progressively limiting frequency selection opportunities.

Because the system uses software defined radio, its parameters can be readily adapted to experience, the Commission's evolving requirements, and shifting market demand. The system can be developed in an evolutionary way in response to market demands and without the discombobulations created when the Commission is forced to take the drastic step of moving out users of older technologies to make room for newer ones. To provide an additional degree of security regarding interference concerns, Shared Spectrum suggests that initially smart radios be operated on a licensed system basis with central control over the software in each transceiver so that the software can be adjusted instantly to respond to any harmful interference that may be experienced or to any direction by the Commission. After experience has demonstrated to all that the technology can be operated with complete confidence, then individual transceivers should be permitted to operate on an unlicensed basis.

**Sufficient Spectrum Should Be Authorized for Cognitive Radios**

To be viable in the marketplace, Cognitive Radios must provide comparable link availability (as well as performance improvements) compared to existing equipment. Since Cognitive Radios are not Primary spectrum users, Cognitive Radios can only obtain high availability by being able to access multiple spectrum bands. For example, suppose there were several bands being considered for Cognitive Radio use, and each band was used 10% of the time or in 10% of the locations by the Primary users. Then at least two such bands would need to be available to the Cognitive Radio for it to achieve 99% availability.

Moreover, the critical Cognitive Radio benefit is the ability to increase link range by allowing use of the VHF and UHF spectrum. Limited link range (and not spectrum quantity) is often the most significant cost driver in the deployment of wireless systems. Cognitive Radio techniques are probably the only approach that will enable cost-effective reuse of the VHF and UHF spectrum.

Furthermore, the frequency agility of cognitive radios provides more efficient use of the spectrum since the radios can adjust to the relative use in each location of frequency bands to accommodate the various relative levels of primary use of each band. And over time, it adjusts seamlessly to differing increases in primary use in each band. Such adjustment are inherent products of the technology and do not require the Commission to undertake re-allotment proceedings to re-apportion the spectrum.

Therefore, the Commission should adopt the strategy of opening one or two spectrum bands for initial Cognitive Radio testing, and then open multiple bands for

Cognitive Radio use. These final bands should include significant spectrum in the VHF and UHF bands.

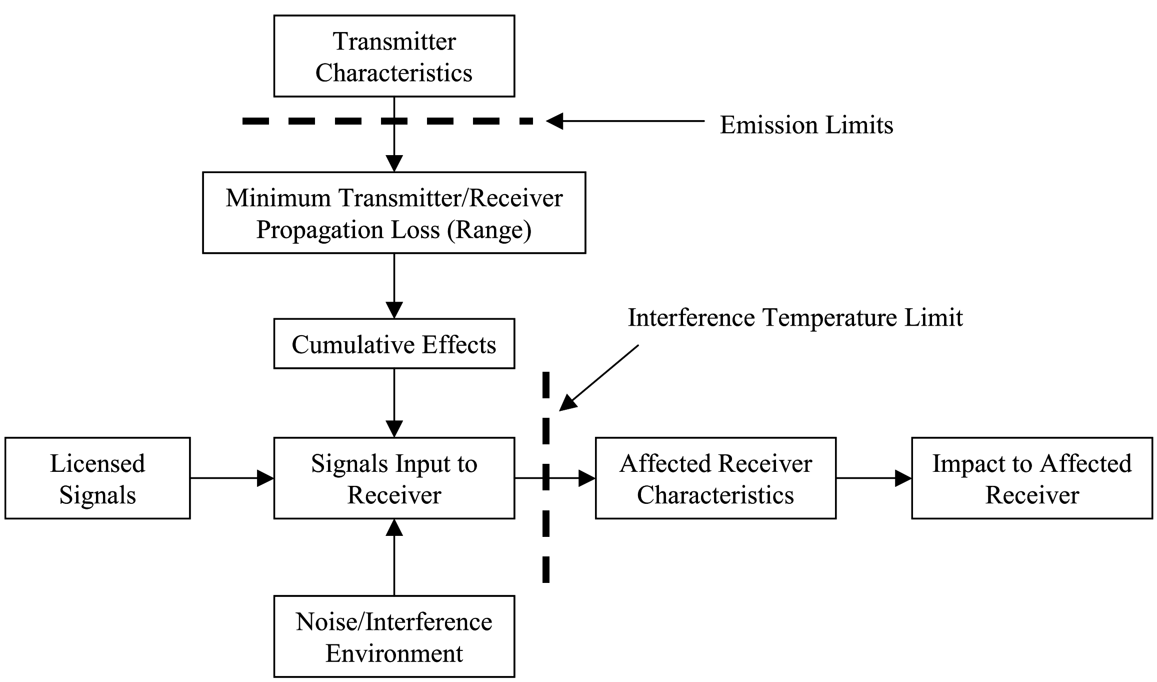
**<u>Secondary Markets Should Be Opened to Existing Licensees But Not Allowed to Become a Vehicle for Monopoly Control</u>**

Shared Spectrum agrees that secondary markets should be open to existing licensees for sharing of bands in which they already operate on a licensed basis. But the Commission should be careful, in doing so, not to award exclusive control over secondary users to existing licensees. Existing licensees do not, and should not, own the spectrum they use. They are merely given the right to use the spectrum in ways limited by frequency, location, and time and exclude other services only to the extent that such services may cause them harmful interference. Allowing secondary use must not be the occasion for enlarging their legal rights to comprise what essentially would be the ownership clearly forbidden by the Communications Act and sound public policy. Nothing will thwart a new technology more effectively than giving exclusive control over it to entrenched parties already providing services in the same field.

**Interference Management Should Be Based on Receiver Levels Rather Than Transmitter Levels**

The concept of limiting received power levels instead of limiting transmitted power levels is the key to new spectrum access methods. Greater spectrum access will be achieved by allowing transceivers to estimate dynamically interference-related parameters to determine appropriate transmit frequencies and power levels. In contrast, the present method sets the transmit frequencies and power levels for all scenarios by considering the interference in the worse case scenario (based on conservative analysis assuming the worse case for all interference related parameters). Use of this very conservative regulatory approach has led to the very low spectrum utilization that exists today. This difficulty was unavoidable before the development of low power, low cost computing and broad bandwidth RF devices.  These technology shortfalls, however, no longer exist.

The functional elements related to interference to an “Affected Receiver” by a transmitter are shown in Figure 1.  These elements are used to determine the interference between a “Transceiver” and the “Affected Receiver”, which then can be used to determine what transmit frequency and power level is acceptable.  The transmitter characteristics include the power level, emission type, bandwidth, duty cycle, spurious emissions and other characteristics.  The propagation loss between the Transceiver and Affected Receiver then determines the undesired signal level at the Affected Receiver.  When there are multiple transmitters, there will be a cumulative effect that will depend on the number of transmitters, their duty cycle, and the propagation conditions.  This undesired signal is input to the Affected Receiver along with the desired “Licensed Signal” and noise from the environment.  The noise consists of pre-amp thermal noise, natural noise, and man-made noise.






-

**Figure 1  Elements related to interference and different regulatory methods (Emission Limits and Interference Temperature Limit).**

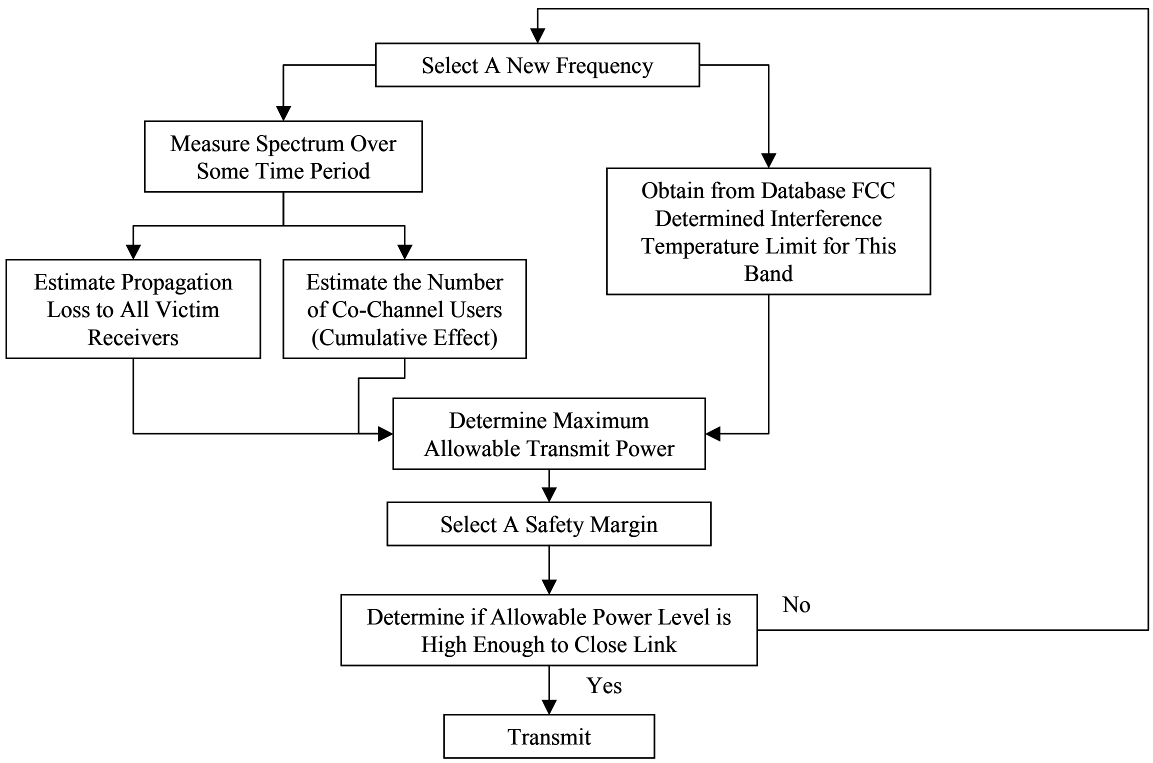
Currently the FCC minimizes interference by limiting the transmitter characteristics. These Emission Limits were premised on historical analyses that involve estimating the above functional elements (propagation effects, cumulative effects, Licensed signal characteristics, the noise environment, and the Affected Receiver characteristics). Because of the wide range of potential radio usage, there is large uncertainty in the functional element values, and the FCC must use conservative values. Using overly conservative values greatly limits spectrum use, and is the root cause of the low spectrum usage seen today.

The Commission proposes to minimize interference by limiting the level of undesired signal to the Affected Receiver (see Figure 1). The fundamental difference is that it enables the transmitter to estimate some or all of the functional elements (propagation effects, cumulative effects, Licensed signal characteristics, the noise environment, and the Affected Receiver characteristics), and then adjust its transmission characteristics to avoid interference. Instead of making worse case assumptions in all instances, the actual conditions can be used.

## 1 Open Loop Interference Temperature Architecture

Figure 2 below shows the Open Loop Interference Temperature system logic. After selection of a frequency, the Transceiver measures the spectrum over a time period. This includes the co-channel, adjacent channel, harmonic, and any other frequencies that need to be examined as part of the required regulatory spectrum behavior. These measurements are used to estimate the propagation loss to the

Affected Receiver (using an assumed value of the Affected Receiver's transmit power ($P_{Affected}$), and to estimate the number of other Transceivers in the area.




The Transceiver's maximum allowable transmit power is then

$$P_{max\ TX} = P_{allowable\ interference} + P_{Affected} - P_{measured} \qquad (1)$$

The allowable interference power ($P_{allowable\ interference}$ in dBm) is related to the Interference Temperature (Ti) if the Affected Receiver and the Transceiver have the same signal bandwidths (B).[1] In the equation below, k is Boltzmann's constant (1.38 x $10^{-23}$ J/K) and $T_I$ is the Interference Temperature in Kelvin.

$$P_{allowable\ interference} = 10*\log10(k * T_I * B) + 30 \qquad (2)$$

Depending on the spectrum behavior used, the Transceiver's maximum allowable transmit power is minimum of the values calculated for the co-channel and adjacent channels (adjusted by the adjacent channel isolation of the Transceiver and the

[1] The Transceiver' maximum transmit power can be increased by the bandwidth ratio if the it's signal bandwidth is larger that than Affected Receiver's signal bandwidth.

Affected Receiver). The Transceiver's maximum allowable power is then reduced by the estimated number of other users (based on the spectrum's time history measurements).

A safety margin is then used to reduce the Transceiver's maximum allowable transmit power. This accounts for rapid changes in the propagation due to mobility, uncertainties in the assumed value of the Affected Receiver's transmit power ($P_{Affected}$), and other factors.

If the resulting Transceiver's maximum allowable transmit power is high enough to close the desired link, then the frequency is used. Otherwise, another frequency is selected and the entire process repeats.

## 2 Interference Temperature Levels

The Interference Temperature Limit should be initially set to a low value, where the noise is dominated by RF-front end noise. In this case, the standard Gaussian noise detectors and other measurement methods are adequate.[2]

In general, unintended signals that input to the Affected Receiver include the cumulative power of all distant (not strong enough to demodulate) licensed signals, emissions from proximate electronic devices (computers, power lines, power converters, etc), sideband and harmonic distortion from other transmitters, and receiver pre-amplifier noise.

There have been extensive measurements of unintended, man-made noise signal levels that culminated in the International Telecommunications Union (ITU) noise

[2] Interference Temperature is a measure of signal power per unit bandwidth. Units of Watts/Hz, dBm/Hz or Kelvin can be used. The total noise power (N) over a frequency range (b) is equal to:

$N=kTb$ (W)

where k is Boltzmann's constant ($1.38 \times 10^{-23}$ J /K). Antennas, John D. Krauss, page 847 model[3] and other noise models[4]. These findings show that the median noise level varies with frequency and location (urban, suburban, and rural). Typical noise levels (in units of Noise Figure (dB)) are shown in Figure 2 and Figure 3. These ambient noise levels are high below 1,000 MHz. As shown in Figure 3, the emissions from nearby devices (a vehicle at 50 feet in this example) can increase the noise figure to 40 dB to 50 dB.

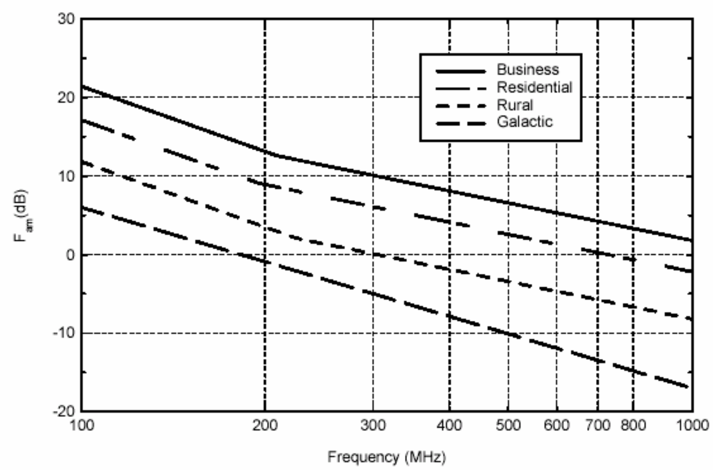
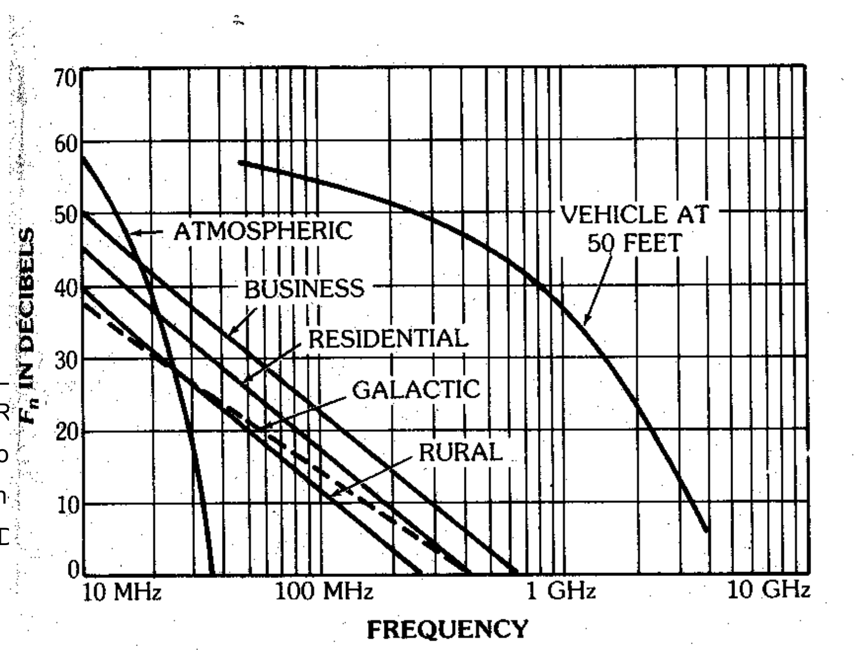



**Figure 2 Median value of average noise power expected from various sources (omni-directional antenna near the surface).[4]**




[3] CCIR ... ittee, International Teleco...

[4] "Man... nd R. A. D...



-

**Figure 3 Noise data including large emissions from a vehicle at 50 feet.**[5]

Ambient noise level statistics other than the median values, however, are not well known. Experimental studies indicate that the noise levels in specific scenarios don't necessarily follow the ITU model. For example, in the HF band the ambient noise can be low in urban areas and can be high in rural areas.[6] The dominant noise sources in this study were power lines, which was time varying and erratic. Furthermore, the noise levels inside buildings, where the vast majority of consumer wireless devices are used, is not reported in the literature. Shared Spectrum's measurements indicates that these noise levels will be much higher than the levels shown

We believe that if detailed noise statistic experiments were made at a large in Figure 2 and Figure 3 because of the proximity of computers and other devices number of locations, that the results would be similar to the hypothetical results shown in Figure 4 and Figure 5. These estimates are based on Shared Spectrum's experience making spectrum occupancy measurements over the last several years, and are representative of frequencies below 500 MHz. Figure 4 shows the number of locations versus the ambient median noise level in dBm/Hz (assuming that the system has a 7 dB noise figure), while Figure 5 shows the cumulative probability of cases with noise level less than the noise level shown in the X-axis. The high noise cases have strong emissions from proximate electronic devices, while the low noise case are dominated by the receiver's RF front-end noise (pre-amplifier noise, cable, filter, and RF switch losses).

---

[5] Reference Data for Engineers: Radio, Electronics, Computer and Communications, Eight Edition, page 32-11, Sams Publishing, 1993.

[6] "An Examination of Man Made Radio Noise at 37 HF Receiver Sites", W.R. Vincent, R.W. Adler, and G.F. Munsch, Navel Postgraduate School Report, NPS-EC-03-006, November 2003.

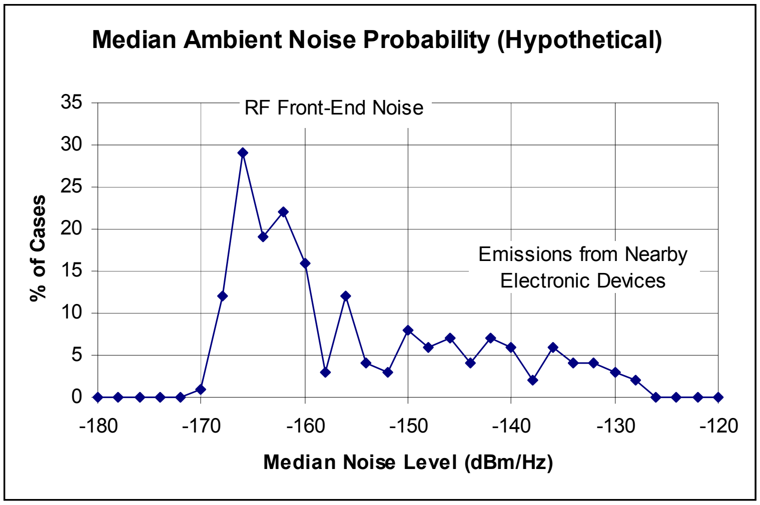



**Figure 4 Hypothetical received noise level probability for multiple test locations versus median noise level.**

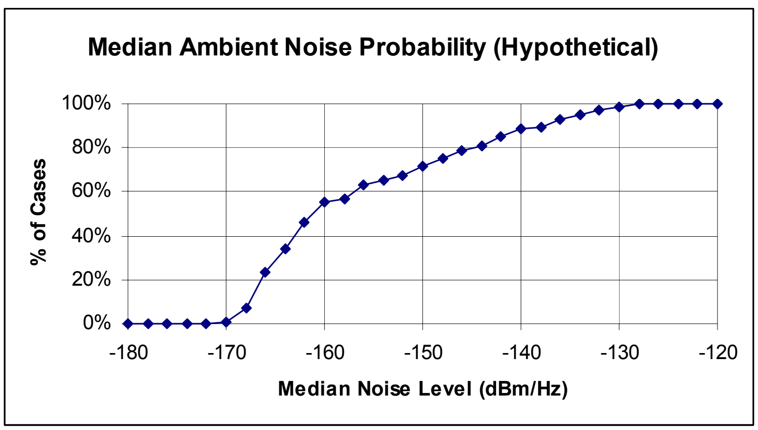



**Figure 5 Hypothetical received noise level cumulative probability for multiple test locations versus median noise level.**

The median noise level in this example in –161 dBm/Hz, which is a noise figure of approximately 13 dB. Comparing with Figure 2, this corresponds to the case of a frequency of 200 MHz in a “business” area.



-

The important point is that in many locations, the noise level will be set by RF-front end noise. The probability of this will be high enough, that the existing spectrum users will argue for a low Interference Temperature.

Shared Spectrum suggests that the Interference Temperature Limit should be approximately 3 dB below the typical effective input power caused by the Affected Receiver's pre-amplifier in a band. **Error! Reference source not found.** shows a list of pre-amplifier noise values and the associated Interference Temperature limits. The 3 dB value provides a balance between the impact to the Affected Receiver and ability of the Transceiver to transmit reasonable power levels. In bands where the ambient noise level is low and the Affected Receiver link margins are low (high bandwidth satellite downlinks for example), the 3 dB value would be increased to a larger value or the Interference Temperature operation would not be authorized.

### Dynamic Sharing Will Bring Substantial Public Benefits

The introduction of the new sharing technology would generate substantial, broad-based economic benefits for the nation both in the long and short-term. Short-term benefits would arise from: (1) the specific benefits that would flow to the public safety entities (and those they serve) whose operations would be made more efficient by use of the technology (2) the efficiencies that it would bring to a wide variety of radio system applications throughout the economy. When each new service in turn must run the gauntlet of a separate regulatory process, the resulting risks and the delays strongly dampen the innovative impetus. Shared Spectrum is developing a technology that permits expansion along several trajectories depending on acceptance in market factors. Below we explain each of these points.

One relatively short-term beneficial output of the technology would be a specific system providing communications infrastructure for public safety agencies at major incidents such as terrorist attack, large forest fires or major airplane crashes. The system would provide public safety agencies the ability to use commercial off-the-shelf hardware and software, such as personal computers and PDAs, to support high-speed (50 Mbps), high-capacity (multiple simultaneous paths), relatively long range (10s of kilometers), interoperable data communications. Operating infrastructure could be established within hours at large incidents. Similar infrastructure could be established in urban areas to support ongoing communications needs as well as to provide support during such incidents.

The growth of the Internet and the widespread use of wireless LANs, most notably WiFi (IEEE 802.11), has resulted in today's environment in which most portable computers come with software support for wireless media, TCP/IP, and client software for email, conferencing, and web access.[7] The proposed system would allow a public safety agency to install a PC Card device into a personal computer and establish communications with the infrastructure using the preexisting software in the personal computer. Unlike the case of commercial 802.11 wireless LANs, which are restricted by FCC-imposed power limits to short range operations—typically less than 100 meters, the proposed system would have a range of many kilometers. Similarly, the system could support multiple connections at the same time. The familiar 802.11b wireless LAN technology supports only three simultaneous transmissions in the same area—setting a limit on the total capacity at any hotspot.

Public safety agencies have begun to use wireless LAN technology in several modes including for routine local networking in offices, for communications to mobile

[7] All major personal computer operating systems, MS Windows, Apple OS-X, and Linux support both 802.11 PCC ard interfaces and TCP/IP connectivity over 802.11 devices.

units needing data capabilities, and for use at incidents. Use of a wireless LAN at an incident poses several problems that are not encountered in routine use:

- infrastructure may be lacking,
- infrastructure coverage may be inadequate, and
- radio spectrum may not be available.

Wireless LANs require access points (APs) with radio connections on one side and backhaul connections to the wider Internet on the other. Conventional APs are installed where the need for communications is foreseen in advance and have limited range. Conventional APs share the radio spectrum with other unlicensed communications devices, such as cordless telephones and radio amateurs, and with non-communications devices such as microwave ovens. Thus, it is likely that many incidents will occur in areas lacking preexisting access point coverage. Conventional wireless LANs at incidents may have to share radio spectrum with wireless LANs in nearby offices or used by others, such as news media or bystanders, located at or near the incident scene.

The project will develop infrastructure that remedies these shortcomings. The system infrastructure would:

- be able to operate on spectrum not shared with other wireless LAN users,
- provide coverage of 10 to 20 km from a single access point,
- be deployable on short notice, and
- provide incident management tools such as web servers, email connectivity, chat tools, and shared databases.

Paired with the infrastructure would be matching mobile radio units with PC Card, USB, or Ethernet interfaces that could be installed in or connected to portable computers and similar user devices. Client software would also be made available that would permit access to applications for those devices lacking the necessary software.

The basic mode of operation would be for a unit arriving at the incident to obtain a PC Card from the incident commander, plug that PC Card into a computer, and establish connectivity. The unit would then have reliable Internet connectivity back to the unit's own home base and to the wider Internet. The unit would also have access to the communication tools, such as web servers and databases, collocated with the base station. These tools would provide the incident commander with an efficient and reliable mechanism for communication with units and unit commanders from various jurisdictions.

Large incidents occur regularly. For example, the California Department of Forests and Fires (CDF) reports that it was involved with the suppression of 93 fires covering more that 300 acres during the year 2002.[8] The CDF maintains 11 mobile kitchens each capable of serving 2,000 people per day.

Interoperability poses a consistent problem in public safety communications. The public safety interoperability problem has been recognized for decades but the problem persists because of multiple technical, economic, and social constraints. The proposed system would provide a valuable interoperability asset, one capable of supporting units from many jurisdictions, without requiring advance investment or training by those jurisdictions.

Quantifying the benefits from improved communications at major incidents poses difficulties—there is no simple mapping from communication improvements to public safety system performance to property and lives saved. However, we can estimate rough bounds. FEMA reports that direct property loss in the United States due to fires

[8] http://www.fire.ca.gov/FireEmergencyResponse/HistoricalStatistics/HistoricalStatistics.asp.

was $10.3 billion in 2002. In addition, 3,380 civilian deaths were caused by fire. There are about 300,000 full-time professional firefighters.[9] Major incidents comprise only a small fraction of fires and a larger proportion of the costs of fires. A 1% decrease in direct costs of fires would generate annual benefits of $100 million per year. Discounting an annual flow of such benefits to the present at 2% yields a net present value of benefits of $5 billion.[10]

More fundamentally, the technology will provide an important new tool in managing the radio spectrum resource, i.e. the range of usable radio frequencies and the permission to operate transmitters on those frequencies. The radio spectrum is often regarded as a flow resource divided by elements of time, space, and frequency.[11] Originally, the radio spectrum was divided among alternative users by means of administrative tools that were based on static information such as written databases. Such tools reflected the information technology available at the time they were developed. They also reflect tradeoffs between administrative cost, system reliability, and system quality and political choices regarding the amount of radio spectrum that should be made available to various services such as broadcasting, cellular, public safety. As with many information systems, the radio spectrum management system has substantial inertia and still depends on mechanisms that were forged in a pre-computer world. Radio technology underlies key portions of the economy including broadcasting, satellite and cable TV, mobile communications, emergency communications, and air traffic control. Spectrum is to communications as petroleum is to transportation—a key

---

[9] Fire Data Web page at http://www.usfa.fema.gov/inside-usfa/nfdc/nfdc-data11.shtm.

[10] A 2% interest rate may seem low to one familiar with typical high-tech venture funding. However, we believe it to be the appropriate rate for such social benefits. See The Rate of Discount for Evaluating Public projects, by R. F. Mikesell, AEI, 1977.

[11] See http://www.itu.int/ITU-R/ and FCC Radio Spectrum Home Page, http://www.fcc.gov/oet/spectrum/.

input.   It is not unreasonable to conclude that use of the radio spectrum contributes directly to about 5% of the GDP and even more indirectly.  Given that the annual GDP is $11 trillion, this amounts to annual value added of $550 billion.

The project will deliver a new capability— a system able to manage the use of spectrum on a non-interference basis dynamically, matching spectrum demand to spectrum availability on a time scale of minutes rather than the decades of the traditional system, over a wide swath of spectrum and geography.  Such capabilities can be used by the Commission to permit opportunistic but non-interfering spectrum use to authorize dynamically subscriber operation by service providers to manage the subleasing of their radio spectrum.  Even a slight increase in the efficiency of the use of the radio spectrum would generate annual benefits of billions of dollars per year.  The system will facilitate access to and use of spectrum by a variety of users.  In economists' jargon, it increases the supply of spectrum.

Adoption of the framework proposed here will permit increase in spectrum use to develop in a market-driven evolutionary way.  There will be no need for the Commission to undertake the increasingly painful process of kicking out older and less efficient services band by band in order to make spectrum available for new technology that better serves current needs.  Dynamic sharing will permit the introduction of substantial additional communications capacity as the market demands it without the need to order existing users to cease and desist their operations.

## CONCLUSION

The Commission should adopt a policy in favor of authorizing frequency-agile cognitive radio systems using spatial and temporal holes, initially on a licensed basis, to operate in substantial portions of the VHF and UHF bands.

Respectfully submitted,

Shared Spectrum Company

William J. Byrnes

7921 Old Falls Road
McLean, VA 22102-2414
703-821-3242

Mark A. McHenry
Alexe E. Leu
8133 Leesburg Pike, Suite 220
Vienna, VA 22182
703-761-2818 x 103

April 5, 2004